

<b>BROOKHAVEN NATIONAL LABORATORY</b> Safety & Health Services Division		NUMBER <b>IH99150</b>
<b>INDUSTRIAL HYGIENE GROUP</b> Standard Operating Procedure: Field Procedure		REVISION <b>SHSD FINAL rev 0</b>
SUBJECT:	GENERAL PRINCIPLES:	DATE <b>01/25/02</b>
<b>Radio-frequency and Microwave Field Measurement Principles</b>		PAGE <b>1 OF 20</b>

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### 1.0 Purpose/Scope

This procedure provides a standardized method for conducting area surveys with direct reading meters for radio frequencies. It should be used in conjunction with the SBMS Subject Area *Radio Frequencies (RF) and Microwaves* and an Instrument Operation procedure in the series such as IH SOP for the Narda Model 8718B Electromagnetic Radiation Survey Meter, Holaday HI-3702 Clamp on Induced Current Meter, or the HI4416 System readout.

An area survey meter should be used to determine baseline microwave field levels and area levels to evaluate the need for area warning posting, locate problem microwave sources, leaks, and measure the effectiveness of engineering controls. It can be used as a screening tool to determine the need for additional personal monitoring and to delineate controlled areas.

Time averaging dosimeters are not readily available for RF/microwave exposure determination. However, alarming monitors are available. They should be worn when it is not clear that the levels indicate that the exposure will exceed the OEL. This area survey meter can be used as a screening tool to identify those areas that may require a dosimeter alarm as well as identify the need for engineering controls, posting, as well as work practices and procedures. Documentation of the duration of the activity, and/or length of time in area is extremely important since the standards are based on exposure duration of 6 minutes except for frequencies from 15 GHz to 300 GHz where the duration is calculated.

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## 2.0 Responsibilities

- 2.1 Use of this SOP and an Instrument Operation SOP for a particular meter is limited to persons who act under the direction of a competent hazard assessor and who have demonstrated the competency to satisfactorily use the procedures and meter, as evidenced by experience and training. Qualification must be demonstrated to the satisfaction of their supervision or existing qualification criteria set by the employee's organization.
- 2.2 Personnel that perform exposure monitoring with this procedure are responsible to follow all steps in this procedure.
- 2.3 The data collected using this meter must have an appropriate evaluation of the hazard and risk by a skilled Industrial Hygiene professional.

## 3.0 Definitions

- 3.1 *Averaging time ( $T_{avg}$ ):* The appropriate time period over which exposure is averaged for purposes of determining compliance with threshold limit values (TLVs).
- 3.2 *Duty factor:* The ratio of pulse duration to the pulse period of a periodic pulse train. A duty factor of 1.0 corresponds to continuous-wave (CW) operations.
- 3.3 *Electric field (E):* A field vector quantity that represents the force (f) on a positive test charge (q) at a point divided by the charge.

$$E = f/q$$

Electric field strength is expressed in units of volts per meter (V/m).

- 3.4 *Exposure:* The subjection of a person to an electric, or electromagnetic fields or to contact currents either than those originating from physiological processes in the body and other natural phenomena.
- 3.5 *Exposure, partial-body:* Exposure that results when RF fields are substantially non-uniform over the body. Fields that are non-uniform over volumes comparable to the human body may occur due to highly directional sources, standing waves, re-radiating sources, or exposure in a near field region of a radiating structure. See (RF "hot spot.")
- 3.6 *Far-field region:* That region of the field of an antenna or source where the angular field distribution is essentially independent of the distance from the antenna. In this region, also called the free space region, the field has a predominantly plane-wave characteristic, i.e., locally uniform distributions of electric field strength and magnetic field strength in planes transverse to the direction of propagation.
- 3.7 *Hertz (Hz):* The unit for expressing frequency, f. One hertz equals one cycle per second.

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3.8 *Magnetic field strength (H)*: A vector that is equal to the magnetic flux density divided by the permeability of the medium. Magnetic field strength is expressed in units of amperes per meter (A/m).

3.9 *Near-field region*: A region generally in close proximity to a source or radiating structure, in which the electric and magnetic fields do not have a substantially plane-wave characteristic, but vary considerably from point to point. The near field is further divided into the reactive near field region, which is closest to the radiating structure and that contains most or nearly all of the stored energy, and the radiating near field region where the radiation field predominates over the reactive field, but lacks substantial plane-wave character and is complicated in structure.

NOTE: For most antennas, the outer boundary of the reactive field region is commonly taken to exist at a distance of one-half wavelength from the antenna surface.

3.10 *Occupational Exposure Limit*: The maximum time weighted average (TWA) or ceiling value exposure permitted for employee exposure, based on the less of the OSHA Permissible Exposure Limits (PEL) or ACGIH Threshold Limit Value (TLV). OSHA does not have a RF/Microwave field standard for all wavelengths. BNL has adopted the guidelines that are found in the RF/Microwave subject area. The rms and peak electric and magnetic field strengths, their squares, or the plane-wave equivalent power densities associated with these fields and the induced and contact currents to which a person may be exposed without harmful effects for their working lifetime.

3.11 *Power density (s) or electromagnetic power flux density*: Power per unit area normal to the direction of propagation. This is usually expressed in units of watts per square meter ( $W/m^2$ ) or microwatts per square centimeter ( $\mu W/cm^2$ ). For plane wave power density, electric field strength (e) and magnetic field strength (H) are related by the impedance of free space, i.e., 377 ohms.

$$S = E^2/377$$

$$S = 377H^2$$

Where E and H are expressed in units of V/m and A/m respectively and S in units of  $W/m^2$ . Although many survey instruments indicate power density units, the actual quantities measured are E or  $E^2$  or H or  $H^2$ .

3.12 *Power density, average (temporal)*: The instantaneous power density integrated over a source repetition period.

3.13 *RF Hotspots*: A highly localized area of relatively more intense radio-frequency radiation that manifests itself in two principal ways:

- a) The presence of intense electric or magnetic fields immediately adjacent to conductive objects that are immersed in lower intensity ambient fields (often referred to as re-radiation), and

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b) Localized areas, not necessarily immediately close to conductive objects, in which there is a concentration of radio-frequency fields cause by reflections and/or narrow beams produced by high-gain radiating antennas or other highly directional sources.

In both cases the fields are characterize by very rapid changes in field strength with distance. RF hot spots are normally associated with very non-uniform exposure of the body (partial body exposure). This is not to be confused with an actual thermal hot spot within the absorbing body.

3.14 *Radio frequency (RF)*: A frequency that is used for radio transmission.

Note: Although the RF spectrum is formally defined in terms of frequency from 0 to 3000 GHz, for purposes of this standard, the frequency range of interest is 30 KHz to 300 GHz.

3.15 *Re-radiated field*: An electromagnetic field resulting from currents induced in a secondary, predominantly conducting, object by electromagnetic waves incident on that object from one or more primary radiating structures or antennas. Re-radiated fields are sometimes called “reflected” or “scattered fields”. The scattering object is sometimes called a re-radiator or “secondary radiator. (See Scatter radiation).

3.16 *Root-mean-square (rms)*: The effective value associated with joule heating, of a periodic electromagnetic wave. The rms value is obtained by taking the square root of the mean of the squared value of a function.

3.17 *Spatial averaging*: The rms of the field over an area equivalent to the vertical cross section of the adult human body, as applied to the measurement of electric or magnetic fields in the assessment of whole-body exposure. The spatial average is measured by scanning (with a suitable measurement probe) a planar area equivalent to the area occupied by a standing adult human (projected area). In most instances, a simple vertical, linear scan of the fields over a 2 meter height (approximately 6 feet), through the center of the projected area, will be sufficient for determining compliance with the threshold limit values.

3.18 *Specific absorption*: The quotient of the incremental energy (dW) absorbed by (dissipated in) an incremental mass (dm) contained in a volume (dV) of a given density.

3.19 *Specific absorption rate (SAR)*: The time derivative of the incremental energy dW absorbed by (dissipated in) an incremental mass (dm) contained in a volume element (dV) of given density ( $\rho$ ).

$$SAR = d/dt(dW/dm) = d/dt(dW/ \rho dv)$$

SAR is expressed in units of watts per kilogram (W/kg).

3.20 *Wavelength ( $\lambda$ )*: Of a monochromatic wave, the distance between two points of corresponding phase of two consecutive cycles in the direction of propagation. The wavelength ( $\lambda$ ) of an electromagnetic wave is related to the frequency ( $f$ ) and velocity

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( $v$ ) by the expression  $v=f\lambda$ . In free space the velocity of an electromagnetic wave is equal to the speed of light, i.e., approximately  $3 \times 10^8$ .

## 4.0 Prerequisites

### 4.1 Training prior to using this meter:

- 4.1.1 Demonstration of proper operation of the instrument to the satisfaction of the employee's supervision.
- 4.1.2 Other appropriate training for the area to be entered (check with ESH coordinator or FR Representative for the facility).
- 4.1.3 Review of the Radio Frequency /Microwave ESH Standard.

### 4.2 Area Access:

- 4.2.1 Contact the appropriate Facility Support Representative or FS Technician to obtain approval to enter radiological areas.
- 4.2.2 Verify with the appropriate Facility Support Representative or FS Technician if a Work Permit or Radiological Permit is needed or is in effect. If so, review and sign the permit.
- 4.2.3 Use appropriate PPE for area.

## 5.0 Precautions

### 5.1 Hazard Determination:

- 5.1.1 The operation of an RF/microwave meter does not cause exposure to any chemical, physical, or radiological hazards. The meters do not generate Hazardous Waste.
- 5.1.2 The meters are very sensitive and can be burned by entry into fields above their capacity. Approach the source from a low background.
- 5.1.3 The primary hazards from microwave are heating of the body. The eyes and genitals/reproductive organs are the most sensitive. Prolonged exposure to very high sources can result in death to the individual.

### 5.2 Personal Protective Equipment:

- 5.2.1 If high fields are expected, the person doing monitoring should wear the NARDA Alert alarming meter.

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- 5.2.2 Microwave protective clothing is not available. Rely on engineering and administrative controls such as remaining a safe distance from the source as indicated by the direct reading meter.
- 5.2.3 Additional PPE: Other appropriate PPE for hands, feet, skin, head, or eyes may be needed for the area being entered. Check with your ES&H representative.

## **6.0 Procedure**

### **6.1 Determine the need for sampling**

- 6.1.1 A survey is performed for various reason for new or modified installations, changes in the previously surveyed environment, changes in the levels of emitted power or limits, and at a the request of personnel or management.
- 6.1.2 Surveys are performed near a known or intentional emitter (such as an antenna) and near an unintentional emitter to detect a suspected leak.

### **6.2 Obtain information on the source and area prior to monitoring**

#### **6.2.1 Emitters characteristics**

- Frequency
- Power level
- modulation characteristics
- Number of sources
- Spurious Frequencies or harmonics
- Intermittence of output
- Antenna information (e.g., size, beam width, gain, orientation)
- Previous survey results.

#### **6.2.2 Site Characterization**

- Structures
- Occupancy by people
- Barriers, interlocks, signs, and visual or audible alarms
- External areas (such as parking lots, residential areas or any other uncontrolled areas that may receive lower, but measurable emissions).
- Topographical information if applicable
- For directional emitters like parabolic antennas, it is necessary to obtain beam elevation angles. This information is used to plot worst – case results of there are no mechanical means to stop the beam from illuminating people in the area.

### **6.3 Select the appropriate piece of equipment.**

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- 6.3.1 Determine if the known or predicted field strength is within the range of the equipment.
- 6.3.2 Operate the meter as per the BNL Instrument Operation SOP.
- 6.4 **Verify the meter is calibrated as per the Instrument Operation SOP.**
- 6.5 **Check if the instrument can be zeroed.** If the instrument does not read zero, then the probe must be zeroed. This must be done in an area without a microwave field or in a zero field chamber or bag.
- 6.6 **Measurements principles**
  - 6.6.1 Before beginning the survey, allow time to warm up and check the equipment. When using thermocouple-based probes, it is advisable to allow the probe to stabilize to the ambient temperature. Allowing the probe to raise or lower its temperature to the ambient temperature helps minimize “zero drift.”
  - 6.6.2 Ensure that the meter’s batteries are charged enough to complete the survey.
  - 6.6.3 Approach source from a low background. Begin the survey from a distance well beyond the calculated hazard distance. Always begin a survey with the meter set on its highest measurement range. Leave the area if the fields will cause exposure that exceeds the applicable standard.
  - 6.6.4 Keep the probe away from reflective surfaces.
  - 6.6.5 Operator Position: The operator should be further from the source than the probe and positioned to reduce reflection of the sound to the meter. Hold the probe at arms length, not close to the body.
  - 6.6.6 If the direction to the emitter is not known, or if there are multiple emitters, the probe should be held at a 45-degree angle. If there is a single emitter, the probe should be pointed directly at the source to minimize isotropic errors.
  - 6.6.7 Accuracy can be improved by taking the mean reading while rotating the probe about its main axis.
  - 6.6.8 Results should be conservatively rated. If the system error is 2 to 3 dB, then results should assume worst cases. In other words, multiply your readings by (in this case) 1.6 to 2.0. An antenna reflection can increase the field strength by a factor of 4, include this factor in your result.
  - 6.6.9 Take spatially averaged levels.
  - 6.6.10 Take measurements at the employee’s level (whether sitting, standing or bending) to estimate personal exposures and to locate isometric lines of RF field intensity on a sketch for defining area levels. Follow the flow chart in Figure 1 (Attachment 8.1) . Field levels are normally averaged over the whole body. The IEEE/ANSI C95.1 standard allows time averaging, but not whole body averaging, for exposures to the eyes and male testes’ body areas.

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- 6.6.11 Start with the E field measurement: If the frequency is less than 300 MHz, then an H field measurement is required.
- 6.6.12 In exposure situations where the distribution of field strengths or plane-waves equivalent power densities is substantially non-uniform over the body (i.e. partial body exposure), for frequencies less than 300 MHz, determine compliance with the MPE field limits by a spatial average of the exposure fields over the plane occupied by the body but in the absence of the body, where feasible.
- 6.6.13 Non-uniform fields are commonly encountered in reflective conditions such as standing wave fields produced by reflection of fields from the earth or other reflective surfaces. Averaging may be accomplished through the use of real-time data-logging equipment or via manually obtained point measurements.
- 6.6.14 For compliance with OEL standards – the average of a series of ten field strength measurements performed in a vertical line with uniform spacing starting at ground level up to a height of 2 m (~6 feet 8 inches) is sufficient. In practice, this means that field strength measurements should be made at heights above the ground separated by 20 cm (about 8 inches).
- 6.6.15 Take at least 10 measurements along the vertical plane from floor to about 6.5 feet high. Measurements should be at a max of 20 cm (~8 inches ) apart. Determining point of highest concentration.
- 6.6.16 Measurements should be taken at least 8 inches away from the surface of the source.
- 6.6.17 If there is shielding, determine if there are any leaks in the barriers.
- 6.6.18 Determine what typical operating positions are and where maximum exposures are possible. If personnel are never in close proximity to the instrument, then it is not necessary to measure surface levels.
- 6.6.19 **Radio Frequency Surveys (50 to 300 MHz):** When surveying in this frequency range, readings may be affected by the distance between your body and the survey equipment. Specifically, your body becomes a large reflector increasingly affecting the probe as you move into the lower part of this frequency range. For the most accurate measurements in this frequency range, maintain a distance of a few feet between your body and the probe. A simple way to do this is to place the probe on a non-metallic stand near the emitter, keeping the separation between the probe and you.
- 6.6.19.1 Both E-field and H-field readings will be made separately and compared with standard limits. Antennas are normally omni-directional in their radiation patterns, so measurements will be made around the entire area in question. Metallic structures may re-radiate

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and/or reflect the energy present thereby complicating the survey. In the United States the IEEE/ANSI standard also includes limits for induced and contact currents, at frequencies below 100 MHz.

6.6.19.2 Once you are within a distance of  $\lambda/2\pi$  to the antenna, the reactive field components may be greater than 10% of the radiating components, leading to errors of greater than 1 dB. Although the reactive components do not form part of the radiating field strength, they are real and can generate heating effects and/or induced currents.

6.6.20 **Radio Frequency Surveys (3 kHz to 50 MHz):** The problems with reflections off the body that begin to appear at 300 MHz (see *Radio Frequency Surveys – 50 to 300 MHz* above) become increasingly significant as you move into even lower frequencies. Below 10 MHz, the equipment is affected also. For accurate readings, you should:

6.6.20.1 Place the probe next to the meter, coiling up the probe's cable so that all components of the system are in the same strength field and put the entire assembly on a non-metallic stand or totally isolate the meter from the probe using a fiber optic link, which allows the meter to be located away from the probe without conducting the emission through a cable.

6.6.20.2 For low frequency antennas that employ guy wires, there will normally be a field radiated from them that should be measured. The level of the reading will be greatly affected by the measurement distance you use. IEEE/ANSI C95.1 standard recommends a minimum measurement distance of 20 cm from any passive re-radiator and 5 cm from an active radiator. Most other standards and guidance list distances of 5 centimeters.

6.6.20.3 Contact current hazards may be present when there are low (<100 MHz) frequency transmitters and conductive objects that may be touched by personnel. Ungrounded objects may store energy that will be discharged through a person's body when the object is touched. When in doubt, you should check the metallic objects near the antenna. A Contact Current Meter provides the means to test contact currents at frequencies below 30 MHz for all major standards or guidance.

6.6.21 Eliminate factors that result in erroneous measurements of field strength by:

6.6.21.1 Maintaining an adequate separation distance between the probe elements and the field source.

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## 6.7 Recording readings:

- 6.7.1 Use a Direct Reading Sampling Instrument Form (found in the Industrial Hygiene Laboratory) or *equivalent* to record readings and additional required information.
- 6.7.2 Return meter and original sampling form to the SHSD IH Laboratory. Copy goes to the ESH Coordinator.
- 6.7.3 Ensure that a copy of any hazard evaluation report written by a competent person on the survey is sent to the IH Laboratory and the Occupational Medicine Clinic, the department ESH coordinator, and the individuals surveyed.
- 6.7.4 The post-survey report should contain field readings, listing of steps taken before, during and after the survey, and the following:
  - Emitter Information
  - Emitter Purpose
  - Site Map
  - Operational Procedures
  - Field Readings
  - Induced and/or Contact Current Hazards (if emissions are 100 MHz)
  - Outline of Hazardous Areas
  - Existence of Ionizing Radiation
  - Control Procedures (Lockout-Tag out, Permit to Work, etc.)
  - Existence of any other hazards (Fuel Storage, Ordinance, etc.)
  - Hazard Areas
  - Field Readings at Areas Normally Accessible by People
  - Hot Spots
  - Existence and Adequacy of engineering Controls and Warning Signs
  - Use of and Operating Procedures to Control Exposures
  - Drawings, Sketches or Photographs of Area
- 6.7.5 Conclusions and Recommendations: If the survey uncovers potentially hazardous areas, the report should include information on the following as applicable:
  - Placement of warning signs
  - Engineering controls
  - Antenna restriction devices
  - Use of terminations or dummy loads when testing
  - Use of barriers, interlocks and visual/audible alarms

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- Area or personal monitors that continually monitor for excessive fields (should any of the above measures fail)

## **7.0 References**

## **8.0 Attachments**

- 8.1 *Figure 1*
- 8.2 **Non-ionizing Radiation General Information**
- 8.3 **Electromagnetic Radiation Spectrum and Related TLVs**
- 8.4 **Wavelength to Frequency Relationship**

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## 9.0 Documentation

Document Review Tracking Sheet		
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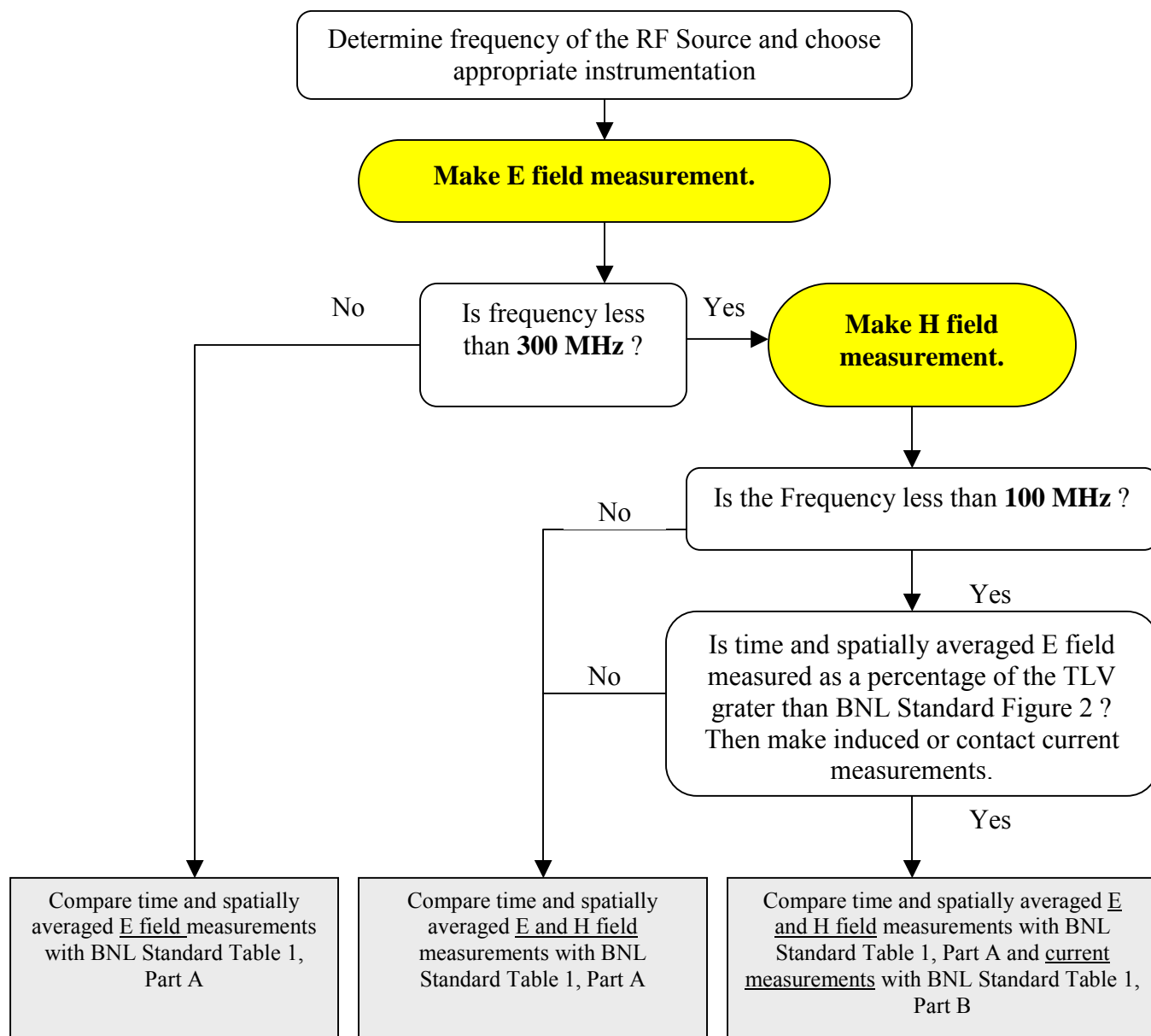
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## Attachment 8.1:

### Figure 1

### Monitoring Strategy Decision Logic



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## Attachment 8.2

### Non-ionizing Radiation

### General Information

#### 1. ANTENNA CHARACTERISTICS

Antennas come in various shapes and sizes but they all operate in the same way. They receive electromagnetic energy from a transmitter through coaxial or wave-guide transmission line. Antenna design is dependent on the application frequency range of operation. The table below gives some of the characteristics of the two major types of antennas – wire and aperture.

ANTENNAS	
Wire Types	Aperture Types
Radiation from currents induced in conductors	Radiation from fields reflected off a surface
Static	Rotating
Low Directivity	High Directivity
Broad Beam width	Narrow Beam width
Dimensions on the order of one wavelength or less	Dimensions on the order of many wavelengths

Aperture antennas come in several forms. Examples include: arrays of low directivity elements, aperture horns, and a shaped reflector or lens illuminated by a broad beam radiator.

There are three distinct areas in front of an antenna that you need to be familiar with. These areas are the reactive near field, the radiating near field, and the far field. All antennas operate as a point source once you are beyond the “Raleigh Distance.” The “Raleigh Distance” is that point where the field strength decreases inversely with the distance and the equivalent power density decreases with the square of the distance.

The near field can extend to a distance of  $D^2/4\gamma$  where D is the antenna diameter.

The power density in the radiating near field can be estimated to be  $4P/A$ . In other words, the maximum power in the near field could be four times the average power over the nominal antenna area. This relationship is shown in the figure below.

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## 2. INSTRUMENTATION CHARACTERISTICS

Instruments are available to cover from 3 kHz to over 100 GHz. ELF and FLF frequency bands are measured by other types of instruments, which are not covered in this document. Different types of detectors are covered in Narda's *RF Electromagnetic Monitors and Measurements*, which is recommended reading when choosing an instrument. Highlights of this document are as follows:

**1. General:** A survey instrument usually contains three distinct parts: Meter, Probe and Cable (or leads). The meter displays the detected levels on an analog or digital display. Meters may include features such as storage of detected levels, audible alarms and built-in test sources. With few exceptions, meters do not form part of the measurement circuit, that is, they do not determine what frequencies or levels are detected. Probes, however, are part of the system that determines what may be measured. Probes are available in designs that detect from one direction (anisotropic) or from all directions (isotropic). Frequencies detected may be very few (narrow bandwidth) or very many (ultra broadband, e.g., 300 kHz to 50 GHz). Dynamic ranges average 30 dB or more and usually only one field component (electric or magnetic) is measured at a time. Cables transmit information from the probe to the meter assemblies. These cables are either shielded copper wires, or (at lower frequency ranges) fiber optic cables. Some low frequency designs exclude cables to maintain accurate readings. Before performing a survey, certain characteristics need consideration, including:

**2. Field Detection:** All probes available measure either the electric (E) or magnetic (H) fields. At high frequencies (300 MHz) some standards require that only one field component be measured (usually E) while at lower frequencies both field components might need to be measured. Additionally, you need to determine if surveys are to be performed with *isotropic or anisotropic* probes. Isotropic probes are usually preferred because mistakes can be made when detecting fields from only one direction. Reflections are not as readily found and can result in considerable measurement errors. When measuring in the near field areas, an isotropic probe may be the only accurate solution because the phase relationship varies rapidly near the antenna.

**3. Frequency Range:** The instrument you choose must cover the frequency or frequencies of the emission. Some emissions may have large harmonics (or multiples) of the main signal, which a narrowband detector may not respond to.

**4. Measurement Range:** Calculations give you an estimate of the field strengths to expect. Most likely, you will want a probe that measures levels both above and below the calculated levels.

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**5. Detection:** probes usually employ either diode-based or thermocouple-based detection. A diode is a non-linear device, which means that over its measurement range it may change from an average detector to a peak detector. As long as the emission is not modulated and it is a single-frequency emission there will not be a large error. If there is a compensating circuit that varies the detector's operation to maintain it in "square law," it will allow the diode to remain accurate in almost any environment. Thermocouple detection is also used to lower (<300 MHz) frequencies. Antenna arrays made up entirely of thermocouple junctions are available for use at higher (1 GHz) frequencies. Thermocouples are linear devices. This means that they will always give true RMS average results, even when used in multiple-emitter applications. Thermocouple array probes operate on energy deposition across their numerous junctions. In this way, they always generate an output that is proportional to the average energy, not matter how narrow the pulse's width is. This is why thermocouple detectors are usually used for measurements on pulse modulated emissions. The major drawback of thermocouples has been inefficiency when compared to diode detectors, meaning that the diode provides a larger output voltage for equivalent field strength. A thermocouple detector therefore exhibits "zero drift," which may be a significant part of a low level reading. Another consideration is that the diode can usually withstand a higher overload level than the thermocouple. This amplifies the need for performing pre-survey calculations, which helps guard against overloading either type of detector.

### **3. SURVEYING UNINTENTIONAL EMITTERS**

Leakage surveys vary considerably from surveys involving known emitters such as antennas. In most cases there are no field calculations that can be performed before the survey.

#### **A. MICROWAVE OVENS**

Microwave oven standards regulate the permissible leakage around the perimeter of an oven door, not human exposure. This leads to a difference in the basic design of the survey equipment. The instruments required to measure this leakage are one-directional or anisotropic. This design helps ensure that only the oven is being tested, rather than having measurements potentially disturbed by other sources in the immediate area.

The U.S. Code of Federal Regulation (CFR) 21 part 1030, specifies the maximum amount of leakage from the oven at distances of 5 cm –  $1.0 \text{ mW/cm}^2$  before the oven is sold and  $5.0 \text{ mW/cm}^2$  throughout its operating life.

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### **Pre-survey Inspections**

Microwave ovens have built-in safety features that should be checked before surveying for leakage. Visual inspections of the door hinges, door seals and latch mechanism should be performed. The latch mechanism can be checked by insuring that the oven stops operation when the door is opened. Excessive food around the door gasket can increase leakage, so ovens need to be kept clean.

### **Oven Surveys**

Microwave ovens are normally tested when operating on their highest power level, and with a load of water (approximately 275 ml.). The test equipment is scanned about any surface of the oven, paying close attention to the area of the door seal while holding the probe horizontally. Most surveying equipment will have a 5 cm spacer to allow you to hold the probe against a surface. Response time for oven meters is usually around one second, but can be up to 3 seconds, so you need to scan the surface at an appropriate speed.

## **B. INDUSTRIAL EQUIPMENT**

Industrial equipment that is used for heating, drying, and sealing is very common in the workplace. These systems can operate from a few Hertz, as in the case of induction heating at foundries, up to hundreds of kilohertz. Sputtering and plasma equipment usually operate at 13.56 MHz and heat sealing or vinyl welding devices usually operate at 27.12 MHz. Before beginning your survey, the emission frequency should be checked with a frequency counter, spectrum analyzer, or manufacturer-supplied data. Spectrum analysis is also useful for determining if equipment is generating multiple emissions, or harmonics, when operated at its highest power level.

With industrial surveys it is important to consider both whole-body averaging and time averaging. Most processes use high power for a short period, which allows for considerably lower averaged exposure levels. When surveying, it is normally beneficial to use a "story pole" that will allow you to mark various survey heights and repeatedly measure at the same point. High power handling is also worth mentioning here. When surveying a device that operates at 27.12 MHz, you will most likely be in the near field. The wavelength at this frequency is approximately 11 meters, which means that, because of the proximity to the source, power may vary greatly with only a slight change of probe position.

The United States has limitations on induced body currents. Such limitations should be considered when planning to perform low frequency (<100 MHz) surveys. In a document published in 1989, the U.S. National Institute of Occupational Safety and Health (NIOSH) stated that measuring the induced body current may provide the most direct indication of absorbed energy. Compliance measurements at frequencies below 100 MHz now include both field and current measurements. If

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field measurements approach standard or guidance limits, you should measure currents.

### **C. TRANSMISSION LINE LEAKAGE**

A common example of leakage measurements is testing wave-guide flanges. Wave-guide flanges and bends are likely points of leakage in high power systems. Gaskets in flanges may deteriorate after cycled over temperature many times. Bends also tend to form stress cracks from temperature and mechanical stress. When testing wave-guide systems, most people will probe as closely as possible to the suspected areas. Normally, defective flanges can be tightened, while bends have to be removed from the system for repair or replacement.

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## Attachment 8.3

### Electromagnetic Radiation Spectrum and Related TLVs

Frequency	Wavelength	Name	
>300 GHz	400 um - <100 nm	Ultraviolet	
>300 GHz	3um –400nm	Light and Near Infrared	
>300 GHz	1 mm	Infrared	
300 GHz	1 mm	Extremely High Frequency (EHF)	
30 GHz	1 mm	SHF	
3 GHz	10 cm	Ultra High Frequency (UHF)	
>300 MHz	1 cm	Microwave	
300 MHz	1 m	Very High Frequency (VHF)	Radio-frequency and Microwave
30 MHz	10 m	High Frequency (HF)	
3 MHz	100 m	Medium MF	
300 kHz	1 m	LF	
<3 kHz	>100 m	Sub-radio Frequency	
3 kHz	10 km	Voice	
30 Hz	1000 km	Extremely Low Frequency	
0 Hz	-	Static	

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## Attachment 8.4

### Wavelength to Frequency Relationship

Frequency			Wavelength	
1 Hz				
10				
1 Hz			3105 miles	3000 km
10 Hz			18,628 miles	30,000 km
60Hz		Powerline	3105 miles	3000 km
1000 Hz	1 kHz		1863 miles	300 km
10 kHz			186 miles	30 km
100 kHz			9836 miles	3000 meters
100 kHz	1MHz	AM radio	984 ft	300 meters
10 MHz			98.4 ft	30 meters
27 MHz		Many RF heat Sealers	36.4 ft	11
30 MHz			32.8Ft	10
100 MHz		FM radio	Ft9.8	3
300 MHz			3.28	1
1000 MHz	1 GHz		11.8 inches	30 cm
2.45 GHz		Microwave ovens	4.8	1.2
10 GHz		Satellite data links	1.18	3
400 GHz		Visible light, red	0.03 mil	(0.75 um; 7500 Angstrom)
750 THz		Visible light, purple		
3,000,000 THz		x-Ray		
50,000,000 THz		Gamma Rays		

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## Contents

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### 1.0 Purpose/Scope

This procedure provides a standardized method for conducting area surveys with direct reading meters for radio frequencies. It should be used in conjunction with the SBMS Subject Area *Radio Frequencies (RF) and Microwaves* and an Instrument Operation procedure in the series such as IH SOP for the Narda Model 8718B Electromagnetic Radiation Survey Meter, Holaday HI-3702 Clamp on Induced Current Meter, or the HI4416 System readout.

An area survey meter should be used to determine baseline microwave field levels and area levels to evaluate the need for area warning posting, locate problem microwave sources, leaks, and measure the effectiveness of engineering controls. It can be used as a screening tool to determine the need for additional personal monitoring and to delineate controlled areas.

Time averaging dosimeters are not readily available for RF/microwave exposure determination. However, alarming monitors are available. They should be worn when it is not clear that the levels indicate that the exposure will exceed the OEL. This area survey meter can be used as a screening tool to identify those areas that may require a dosimeter alarm as well as identify the need for engineering controls, posting, as well as work practices and procedures. Documentation of the duration of the activity, and/or length of time in area is extremely important since the standards are based on exposure duration of 6 minutes except for frequencies from 15 GHz to 300 GHz where the duration is calculated.

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## 2.0 Responsibilities

- 2.1 Use of this SOP and an Instrument Operation SOP for a particular meter is limited to persons who act under the direction of a competent hazard assessor and who have demonstrated the competency to satisfactorily use the procedures and meter, as evidenced by experience and training. Qualification must be demonstrated to the satisfaction of their supervision or existing qualification criteria set by the employee's organization.
- 2.2 Personnel that perform exposure monitoring with this procedure are responsible to follow all steps in this procedure.
- 2.3 The data collected using this meter must have an appropriate evaluation of the hazard and risk by a skilled Industrial Hygiene professional.

## 3.0 Definitions

- 3.1 *Averaging time ( $T_{avg}$ ):* The appropriate time period over which exposure is averaged for purposes of determining compliance with threshold limit values (TLVs).
- 3.2 *Duty factor:* The ratio of pulse duration to the pulse period of a periodic pulse train. A duty factor of 1.0 corresponds to continuous-wave (CW) operations.
- 3.3 *Electric field (E):* A field vector quantity that represents the force (f) on a positive test charge (q) at a point divided by the charge.

$$E = f/q$$

Electric field strength is expressed in units of volts per meter (V/m).

- 3.4 *Exposure:* The subjection of a person to an electric, or electromagnetic fields or to contact currents either than those originating from physiological processes in the body and other natural phenomena.
- 3.5 *Exposure, partial-body:* Exposure that results when RF fields are substantially non-uniform over the body. Fields that are non-uniform over volumes comparable to the human body may occur due to highly directional sources, standing waves, re-radiating sources, or exposure in a near field region of a radiating structure. See (RF "hot spot.")
- 3.6 *Far-field region:* That region of the field of an antenna or source where the angular field distribution is essentially independent of the distance from the antenna. In this region, also called the free space region, the field has a predominantly plane-wave characteristic, i.e., locally uniform distributions of electric field strength and magnetic field strength in planes transverse to the direction of propagation.
- 3.7 *Hertz (Hz):* The unit for expressing frequency, f. One hertz equals one cycle per second.

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3.8 *Magnetic field strength (H)*: A vector that is equal to the magnetic flux density divided by the permeability of the medium. Magnetic field strength is expressed in units of amperes per meter (A/m).

3.9 *Near-field region*: A region generally in close proximity to a source or radiating structure, in which the electric and magnetic fields do not have a substantially plane-wave characteristic, but vary considerably from point to point. The near field is further divided into the reactive near field region, which is closest to the radiating structure and that contains most or nearly all of the stored energy, and the radiating near field region where the radiation field predominates over the reactive field, but lacks substantial plane-wave character and is complicated in structure.

NOTE: For most antennas, the outer boundary of the reactive field region is commonly taken to exist at a distance of one-half wavelength from the antenna surface.

3.10 *Occupational Exposure Limit*: The maximum time weighted average (TWA) or ceiling value exposure permitted for employee exposure, based on the less of the OSHA Permissible Exposure Limits (PEL) or ACGIH Threshold Limit Value (TLV). OSHA does not have a RF/Microwave field standard for all wavelengths. BNL has adopted the guidelines that are found in the RF/Microwave subject area. The rms and peak electric and magnetic field strengths, their squares, or the plane-wave equivalent power densities associated with these fields and the induced and contact currents to which a person may be exposed without harmful effects for their working lifetime.

3.11 *Power density (s) or electromagnetic power flux density*: Power per unit area normal to the direction of propagation. This is usually expressed in units of watts per square meter ( $W/m^2$ ) or microwatts per square centimeter ( $\mu W/cm^2$ ). For plane wave power density, electric field strength (e) and magnetic field strength (H) are related by the impedance of free space, i.e., 377 ohms.

$$S = E^2/377$$

$$S = 377H^2$$

Where E and H are expressed in units of V/m and A/m respectively and S in units of  $W/m^2$ . Although many survey instruments indicate power density units, the actual quantities measured are E or  $E^2$  or H or  $H^2$ .

3.12 *Power density, average (temporal)*: The instantaneous power density integrated over a source repetition period.

3.13 *RF Hotspots*: A highly localized area of relatively more intense radio-frequency radiation that manifests itself in two principal ways:

a) The presence of intense electric or magnetic fields immediately adjacent to conductive objects that are immersed in lower intensity ambient fields (often referred to as re-radiation), and

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b) Localized areas, not necessarily immediately close to conductive objects, in which there is a concentration of radio-frequency fields cause by reflections and/or narrow beams produced by high-gain radiating antennas or other highly directional sources.

In both cases the fields are characterize by very rapid changes in field strength with distance. RF hot spots are normally associated with very non-uniform exposure of the body (partial body exposure). This is not to be confused with an actual thermal hot spot within the absorbing body.

3.14 *Radio frequency (RF)*: A frequency that is used for radio transmission.

Note: Although the RF spectrum is formally defined in terms of frequency from 0 to 3000 GHz, for purposes of this standard, the frequency range of interest is 30 KHz to 300 GHz.

3.15 *Re-radiated field*: An electromagnetic field resulting from currents induced in a secondary, predominantly conducting, object by electromagnetic waves incident on that object from one or more primary radiating structures or antennas. Re-radiated fields are sometimes called “reflected” or “scattered fields”. The scattering object is sometimes called a re-radiator or “secondary radiator. (See Scatter radiation).

3.16 *Root-mean-square (rms)*: The effective value associated with joule heating, of a periodic electromagnetic wave. The rms value is obtained by taking the square root of the mean of the squared value of a function.

3.17 *Spatial averaging*: The rms of the field over an area equivalent to the vertical cross section of the adult human body, as applied to the measurement of electric or magnetic fields in the assessment of whole-body exposure. The spatial average is measured by scanning (with a suitable measurement probe) a planar area equivalent to the area occupied by a standing adult human (projected area). In most instances, a simple vertical, linear scan of the fields over a 2 meter height (approximately 6 feet), through the center of the projected area, will be sufficient for determining compliance with the threshold limit values.

3.18 *Specific absorption*: The quotient of the incremental energy (dW) absorbed by (dissipated in) an incremental mass (dm) contained in a volume (dV) of a given density.

3.19 *Specific absorption rate (SAR)*: The time derivative of the incremental energy dW absorbed by (dissipated in) an incremental mass (dm) contained in a volume element (dV) of given density ( $\rho$ ).

$$SAR = d/dt(dW/dm) = d/dt(dW/ \rho dv)$$

SAR is expressed in units of watts per kilogram (W/kg).

3.20 *Wavelength ( $\lambda$ )*: Of a monochromatic wave, the distance between two points of corresponding phase of two consecutive cycles in the direction of propagation. The wavelength ( $\lambda$ ) of an electromagnetic wave is related to the frequency ( $f$ ) and velocity

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( $v$ ) by the expression  $v=f\lambda$ . In free space the velocity of an electromagnetic wave is equal to the speed of light, i.e., approximately  $3 \times 10^8$ .

## 4.0 Prerequisites

### 4.1 Training prior to using this meter:

- 4.1.1 Demonstration of proper operation of the instrument to the satisfaction of the employee's supervision.
- 4.1.2 Other appropriate training for the area to be entered (check with ESH coordinator or FR Representative for the facility).
- 4.1.3 Review of the Radio Frequency /Microwave ESH Standard.

### 4.2 Area Access:

- 4.2.1 Contact the appropriate Facility Support Representative or FS Technician to obtain approval to enter radiological areas.
- 4.2.2 Verify with the appropriate Facility Support Representative or FS Technician if a Work Permit or Radiological Permit is needed or is in effect. If so, review and sign the permit.
- 4.2.3 Use appropriate PPE for area.

## 5.0 Precautions

### 5.1 Hazard Determination:

- 5.1.1 The operation of an RF/microwave meter does not cause exposure to any chemical, physical, or radiological hazards. The meters do not generate Hazardous Waste.
- 5.1.2 The meters are very sensitive and can be burned by entry into fields above their capacity. Approach the source from a low background.
- 5.1.3 The primary hazards from microwave are heating of the body. The eyes and genitals/reproductive organs are the most sensitive. Prolonged exposure to very high sources can result in death to the individual.

### 5.2 Personal Protective Equipment:

- 5.2.1 If high fields are expected, the person doing monitoring should wear the NARDA Alert alarming meter.

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- 5.2.2 Microwave protective clothing is not available. Rely on engineering and administrative controls such as remaining a safe distance from the source as indicated by the direct reading meter.
- 5.2.3 Additional PPE: Other appropriate PPE for hands, feet, skin, head, or eyes may be needed for the area being entered. Check with your ES&H representative.

## **6.0 Procedure**

### **6.1 Determine the need for sampling**

- 6.1.1 A survey is performed for various reason for new or modified installations, changes in the previously surveyed environment, changes in the levels of emitted power or limits, and at a the request of personnel or management.
- 6.1.2 Surveys are performed near a known or intentional emitter (such as an antenna) and near an unintentional emitter to detect a suspected leak.

### **6.2 Obtain information on the source and area prior to monitoring**

#### **6.2.1 Emitters characteristics**

- Frequency
- Power level
- modulation characteristics
- Number of sources
- Spurious Frequencies or harmonics
- Intermittence of output
- Antenna information (e.g., size, beam width, gain, orientation)
- Previous survey results.

#### **6.2.2 Site Characterization**

- Structures
- Occupancy by people
- Barriers, interlocks, signs, and visual or audible alarms
- External areas (such as parking lots, residential areas or any other uncontrolled areas that may receive lower, but measurable emissions).
- Topographical information if applicable
- For directional emitters like parabolic antennas, it is necessary to obtain beam elevation angles. This information is used to plot worst – case results of there are no mechanical means to stop the beam from illuminating people in the area.

### **6.3 Select the appropriate piece of equipment.**

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- 6.3.1 Determine if the known or predicted field strength is within the range of the equipment.
- 6.3.2 Operate the meter as per the BNL Instrument Operation SOP.
- 6.4 **Verify the meter is calibrated as per the Instrument Operation SOP.**
- 6.5 **Check if the instrument can be zeroed.** If the instrument does not read zero, then the probe must be zeroed. This must be done in an area without a microwave field or in a zero field chamber or bag.
- 6.6 **Measurements principles**
  - 6.6.1 Before beginning the survey, allow time to warm up and check the equipment. When using thermocouple-based probes, it is advisable to allow the probe to stabilize to the ambient temperature. Allowing the probe to raise or lower its temperature to the ambient temperature helps minimize “zero drift.”
  - 6.6.2 Ensure that the meter’s batteries are charged enough to complete the survey.
  - 6.6.3 Approach source from a low background. Begin the survey from a distance well beyond the calculated hazard distance. Always begin a survey with the meter set on its highest measurement range. Leave the area if the fields will cause exposure that exceeds the applicable standard.
  - 6.6.4 Keep the probe away from reflective surfaces.
  - 6.6.5 Operator Position: The operator should be further from the source than the probe and positioned to reduce reflection of the sound to the meter. Hold the probe at arms length, not close to the body.
  - 6.6.6 If the direction to the emitter is not known, or if there are multiple emitters, the probe should be held at a 45-degree angle. If there is a single emitter, the probe should be pointed directly at the source to minimize isotropic errors.
  - 6.6.7 Accuracy can be improved by taking the mean reading while rotating the probe about its main axis.
  - 6.6.8 Results should be conservatively rated. If the system error is 2 to 3 dB, then results should assume worst cases. In other words, multiply your readings by (in this case) 1.6 to 2.0. An antenna reflection can increase the field strength by a factor of 4, include this factor in your result.
  - 6.6.9 Take spatially averaged levels.
  - 6.6.10 Take measurements at the employee’s level (whether sitting, standing or bending) to estimate personal exposures and to locate isometric lines of RF field intensity on a sketch for defining area levels. Follow the flow chart in Figure 1 (Attachment 8.1) . Field levels are normally averaged over the whole body. The IEEE/ANSI C95.1 standard allows time averaging, but not whole body averaging, for exposures to the eyes and male testes’ body areas.

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- 6.6.11 Start with the E field measurement: If the frequency is less than 300 MHz, then an H field measurement is required.
- 6.6.12 In exposure situations where the distribution of field strengths or plane-waves equivalent power densities is substantially non-uniform over the body (i.e. partial body exposure), for frequencies less than 300 MHz, determine compliance with the MPE field limits by a spatial average of the exposure fields over the plane occupied by the body but in the absence of the body, where feasible.
- 6.6.13 Non-uniform fields are commonly encountered in reflective conditions such as standing wave fields produced by reflection of fields from the earth or other reflective surfaces. Averaging may be accomplished through the use of real-time data-logging equipment or via manually obtained point measurements.
- 6.6.14 For compliance with OEL standards – the average of a series of ten field strength measurements performed in a vertical line with uniform spacing starting at ground level up to a height of 2 m (~6 feet 8 inches) is sufficient. In practice, this means that field strength measurements should be made at heights above the ground separated by 20 cm (about 8 inches).
- 6.6.15 Take at least 10 measurements along the vertical plane from floor to about 6.5 feet high. Measurements should be at a max of 20 cm (~8 inches ) apart. Determining point of highest concentration.
- 6.6.16 Measurements should be taken at least 8 inches away from the surface of the source.
- 6.6.17 If there is shielding, determine if there are any leaks in the barriers.
- 6.6.18 Determine what typical operating positions are and where maximum exposures are possible. If personnel are never in close proximity to the instrument, then it is not necessary to measure surface levels.
- 6.6.19 **Radio Frequency Surveys (50 to 300 MHz):** When surveying in this frequency range, readings may be affected by the distance between your body and the survey equipment. Specifically, your body becomes a large reflector increasingly affecting the probe as you move into the lower part of this frequency range. For the most accurate measurements in this frequency range, maintain a distance of a few feet between your body and the probe. A simple way to do this is to place the probe on a non-metallic stand near the emitter, keeping the separation between the probe and you.
- 6.6.19.1 Both E-field and H-field readings will be made separately and compared with standard limits. Antennas are normally omni-directional in their radiation patterns, so measurements will be made around the entire area in question. Metallic structures may re-radiate

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and/or reflect the energy present thereby complicating the survey. In the United States the IEEE/ANSI standard also includes limits for induced and contact currents, at frequencies below 100 MHz.

6.6.19.2 Once you are within a distance of  $\lambda/2\pi$  to the antenna, the reactive field components may be greater than 10% of the radiating components, leading to errors of greater than 1 dB. Although the reactive components do not form part of the radiating field strength, they are real and can generate heating effects and/or induced currents.

6.6.20 **Radio Frequency Surveys (3 kHz to 50 MHz):** The problems with reflections off the body that begin to appear at 300 MHz (see *Radio Frequency Surveys – 50 to 300 MHz* above) become increasingly significant as you move into even lower frequencies. Below 10 MHz, the equipment is affected also. For accurate readings, you should:

6.6.20.1 Place the probe next to the meter, coiling up the probe's cable so that all components of the system are in the same strength field and put the entire assembly on a non-metallic stand or totally isolate the meter from the probe using a fiber optic link, which allows the meter to be located away from the probe without conducting the emission through a cable.

6.6.20.2 For low frequency antennas that employ guy wires, there will normally be a field radiated from them that should be measured. The level of the reading will be greatly affected by the measurement distance you use. IEEE/ANSI C95.1 standard recommends a minimum measurement distance of 20 cm from any passive re-radiator and 5 cm from an active radiator. Most other standards and guidance list distances of 5 centimeters.

6.6.20.3 Contact current hazards may be present when there are low (<100 MHz) frequency transmitters and conductive objects that may be touched by personnel. Ungrounded objects may store energy that will be discharged through a person's body when the object is touched. When in doubt, you should check the metallic objects near the antenna. A Contact Current Meter provides the means to test contact currents at frequencies below 30 MHz for all major standards or guidance.

6.6.21 Eliminate factors that result in erroneous measurements of field strength by:

6.6.21.1 Maintaining an adequate separation distance between the probe elements and the field source.

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## 6.7 Recording readings:

- 6.7.1 Use a Direct Reading Sampling Instrument Form (found in the Industrial Hygiene Laboratory) or *equivalent* to record readings and additional required information.
- 6.7.2 Return meter and original sampling form to the SHSD IH Laboratory. Copy goes to the ESH Coordinator.
- 6.7.3 Ensure that a copy of any hazard evaluation report written by a competent person on the survey is sent to the IH Laboratory and the Occupational Medicine Clinic, the department ESH coordinator, and the individuals surveyed.
- 6.7.4 The post-survey report should contain field readings, listing of steps taken before, during and after the survey, and the following:
  - Emitter Information
  - Emitter Purpose
  - Site Map
  - Operational Procedures
  - Field Readings
  - Induced and/or Contact Current Hazards (if emissions are 100 MHz)
  - Outline of Hazardous Areas
  - Existence of Ionizing Radiation
  - Control Procedures (Lockout-Tag out, Permit to Work, etc.)
  - Existence of any other hazards (Fuel Storage, Ordinance, etc.)
  - Hazard Areas
  - Field Readings at Areas Normally Accessible by People
  - Hot Spots
  - Existence and Adequacy of engineering Controls and Warning Signs
  - Use of and Operating Procedures to Control Exposures
  - Drawings, Sketches or Photographs of Area
- 6.7.5 Conclusions and Recommendations: If the survey uncovers potentially hazardous areas, the report should include information on the following as applicable:
  - Placement of warning signs
  - Engineering controls
  - Antenna restriction devices
  - Use of terminations or dummy loads when testing
  - Use of barriers, interlocks and visual/audible alarms

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- Area or personal monitors that continually monitor for excessive fields (should any of the above measures fail)

## **7.0 References**

## **8.0 Attachments**

- 8.1 *Figure 1*
- 8.2 **Non-ionizing Radiation General Information**
- 8.3 **Electromagnetic Radiation Spectrum and Related TLVs**
- 8.4 **Wavelength to Frequency Relationship**

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## 9.0 Documentation

Document Review Tracking Sheet		
<b>PREPARED BY:</b> <i>(Signature and date on file)</i> <b>N. M. Bernholz</b> <b>Author</b> <b>Date 10/11/01</b>	<b>REVIEWED BY:</b> <i>(Signature and date on file)</i> <b>R. Selvey</b> <b>SHSD IH Group</b> <b>Date 12/05/01</b>	<b>APPROVED BY:</b> <i>(Signature and date on file)</i> <b>R. Selvey</b> <b>SHSD IH Group Leader</b> <b>Date 01/25/02</b>
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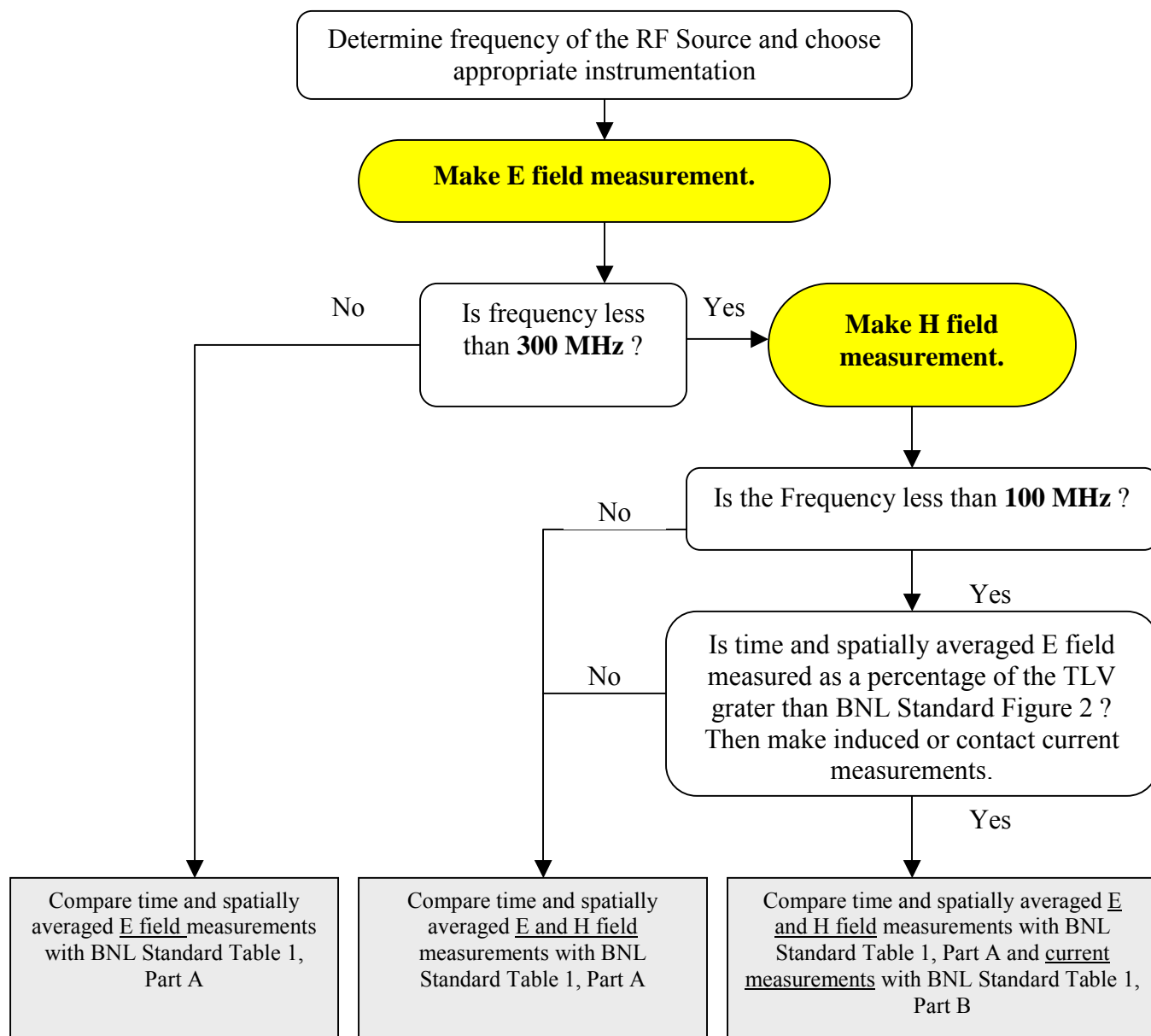
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## Attachment 8.1:

### Figure 1

### Monitoring Strategy Decision Logic



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## Attachment 8.2

### Non-ionizing Radiation

### General Information

#### 1. ANTENNA CHARACTERISTICS

Antennas come in various shapes and sizes but they all operate in the same way. They receive electromagnetic energy from a transmitter through coaxial or wave-guide transmission line. Antenna design is dependent on the application frequency range of operation. The table below gives some of the characteristics of the two major types of antennas – wire and aperture.

ANTENNAS	
Wire Types	Aperture Types
Radiation from currents induced in conductors	Radiation from fields reflected off a surface
Static	Rotating
Low Directivity	High Directivity
Broad Beam width	Narrow Beam width
Dimensions on the order of one wavelength or less	Dimensions on the order of many wavelengths

Aperture antennas come in several forms. Examples include: arrays of low directivity elements, aperture horns, and a shaped reflector or lens illuminated by a broad beam radiator.

There are three distinct areas in front of an antenna that you need to be familiar with. These areas are the reactive near field, the radiating near field, and the far field. All antennas operate as a point source once you are beyond the “Raleigh Distance.” The “Raleigh Distance” is that point where the field strength decreases inversely with the distance and the equivalent power density decreases with the square of the distance.

The near field can extend to a distance of  $D^2/4\gamma$  where D is the antenna diameter.

The power density in the radiating near field can be estimated to be  $4P/A$ . In other words, the maximum power in the near field could be four times the average power over the nominal antenna area. This relationship is shown in the figure below.

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## 2. INSTRUMENTATION CHARACTERISTICS

Instruments are available to cover from 3 kHz to over 100 GHz. ELF and FLF frequency bands are measured by other types of instruments, which are not covered in this document. Different types of detectors are covered in Narda's *RF Electromagnetic Monitors and Measurements*, which is recommended reading when choosing an instrument. Highlights of this document are as follows:

**1. General:** A survey instrument usually contains three distinct parts: Meter, Probe and Cable (or leads). The meter displays the detected levels on an analog or digital display. Meters may include features such as storage of detected levels, audible alarms and built-in test sources. With few exceptions, meters do not form part of the measurement circuit, that is, they do not determine what frequencies or levels are detected. Probes, however, are part of the system that determines what may be measured. Probes are available in designs that detect from one direction (anisotropic) or from all directions (isotropic). Frequencies detected may be very few (narrow bandwidth) or very many (ultra broadband, e.g., 300 kHz to 50 GHz). Dynamic ranges average 30 dB or more and usually only one field component (electric or magnetic) is measured at a time. Cables transmit information from the probe to the meter assemblies. These cables are either shielded copper wires, or (at lower frequency ranges) fiber optic cables. Some low frequency designs exclude cables to maintain accurate readings. Before performing a survey, certain characteristics need consideration, including:

**2. Field Detection:** All probes available measure either the electric (E) or magnetic (H) fields. At high frequencies (300 MHz) some standards require that only one field component be measured (usually E) while at lower frequencies both field components might need to be measured. Additionally, you need to determine if surveys are to be performed with *isotropic or anisotropic* probes. Isotropic probes are usually preferred because mistakes can be made when detecting fields from only one direction. Reflections are not as readily found and can result in considerable measurement errors. When measuring in the near field areas, an isotropic probe may be the only accurate solution because the phase relationship varies rapidly near the antenna.

**3. Frequency Range:** The instrument you choose must cover the frequency or frequencies of the emission. Some emissions may have large harmonics (or multiples) of the main signal, which a narrowband detector may not respond to.

**4. Measurement Range:** Calculations give you an estimate of the field strengths to expect. Most likely, you will want a probe that measures levels both above and below the calculated levels.

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**5. Detection:** probes usually employ either diode-based or thermocouple-based detection. A diode is a non-linear device, which means that over its measurement range it may change from an average detector to a peak detector. As long as the emission is not modulated and it is a single-frequency emission there will not be a large error. If there is a compensating circuit that varies the detector's operation to maintain it in "square law," it will allow the diode to remain accurate in almost any environment. Thermocouple detection is also used to lower (<300 MHz) frequencies. Antenna arrays made up entirely of thermocouple junctions are available for use at higher (1 GHz) frequencies. Thermocouples are linear devices. This means that they will always give true RMS average results, even when used in multiple-emitter applications. Thermocouple array probes operate on energy deposition across their numerous junctions. In this way, they always generate an output that is proportional to the average energy, not matter how narrow the pulse's width is. This is why thermocouple detectors are usually used for measurements on pulse modulated emissions. The major drawback of thermocouples has been inefficiency when compared to diode detectors, meaning that the diode provides a larger output voltage for equivalent field strength. A thermocouple detector therefore exhibits "zero drift," which may be a significant part of a low level reading. Another consideration is that the diode can usually withstand a higher overload level than the thermocouple. This amplifies the need for performing pre-survey calculations, which helps guard against overloading either type of detector.

### **3. SURVEYING UNINTENTIONAL EMITTERS**

Leakage surveys vary considerably from surveys involving known emitters such as antennas. In most cases there are no field calculations that can be performed before the survey.

#### **A. MICROWAVE OVENS**

Microwave oven standards regulate the permissible leakage around the perimeter of an oven door, not human exposure. This leads to a difference in the basic design of the survey equipment. The instruments required to measure this leakage are one-directional or anisotropic. This design helps ensure that only the oven is being tested, rather than having measurements potentially disturbed by other sources in the immediate area.

The U.S. Code of Federal Regulation (CFR) 21 part 1030, specifies the maximum amount of leakage from the oven at distances of 5 cm –  $1.0 \text{ mW/cm}^2$  before the oven is sold and  $5.0 \text{ mW/cm}^2$  throughout its operating life.

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### **Pre-survey Inspections**

Microwave ovens have built-in safety features that should be checked before surveying for leakage. Visual inspections of the door hinges, door seals and latch mechanism should be performed. The latch mechanism can be checked by insuring that the oven stops operation when the door is opened. Excessive food around the door gasket can increase leakage, so ovens need to be kept clean.

### **Oven Surveys**

Microwave ovens are normally tested when operating on their highest power level, and with a load of water (approximately 275 ml.). The test equipment is scanned about any surface of the oven, paying close attention to the area of the door seal while holding the probe horizontally. Most surveying equipment will have a 5 cm spacer to allow you to hold the probe against a surface. Response time for oven meters is usually around one second, but can be up to 3 seconds, so you need to scan the surface at an appropriate speed.

## **B. INDUSTRIAL EQUIPMENT**

Industrial equipment that is used for heating, drying, and sealing is very common in the workplace. These systems can operate from a few Hertz, as in the case of induction heating at foundries, up to hundreds of kilohertz. Sputtering and plasma equipment usually operate at 13.56 MHz and heat sealing or vinyl welding devices usually operate at 27.12 MHz. Before beginning your survey, the emission frequency should be checked with a frequency counter, spectrum analyzer, or manufacturer-supplied data. Spectrum analysis is also useful for determining if equipment is generating multiple emissions, or harmonics, when operated at its highest power level.

With industrial surveys it is important to consider both whole-body averaging and time averaging. Most processes use high power for a short period, which allows for considerably lower averaged exposure levels. When surveying, it is normally beneficial to use a "story pole" that will allow you to mark various survey heights and repeatedly measure at the same point. High power handling is also worth mentioning here. When surveying a device that operates at 27.12 MHz, you will most likely be in the near field. The wavelength at this frequency is approximately 11 meters, which means that, because of the proximity to the source, power may vary greatly with only a slight change of probe position.

The United States has limitations on induced body currents. Such limitations should be considered when planning to perform low frequency (<100 MHz) surveys. In a document published in 1989, the U.S. National Institute of Occupational Safety and Health (NIOSH) stated that measuring the induced body current may provide the most direct indication of absorbed energy. Compliance measurements at frequencies below 100 MHz now include both field and current measurements. If

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field measurements approach standard or guidance limits, you should measure currents.

### **C. TRANSMISSION LINE LEAKAGE**

A common example of leakage measurements is testing wave-guide flanges. Wave-guide flanges and bends are likely points of leakage in high power systems. Gaskets in flanges may deteriorate after cycled over temperature many times. Bends also tend to form stress cracks from temperature and mechanical stress. When testing wave-guide systems, most people will probe as closely as possible to the suspected areas. Normally, defective flanges can be tightened, while bends have to be removed from the system for repair or replacement.

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## Attachment 8.3

### Electromagnetic Radiation Spectrum and Related TLVs

Frequency	Wavelength	Name	
>300 GHz	400 um - <100 nm	Ultraviolet	
>300 GHz	3um –400nm	Light and Near Infrared	
>300 GHz	1 mm	Infrared	
300 GHz	1 mm	Extremely High Frequency (EHF)	
30 GHz	1 mm	SHF	
3 GHz	10 cm	Ultra High Frequency (UHF)	
>300 MHz	1 cm	Microwave	
300 MHz	1 m	Very High Frequency (VHF)	Radio-frequency and Microwave
30 MHz	10 m	High Frequency (HF)	
3 MHz	100 m	Medium MF	
300 kHz	1 m	LF	
<3 kHz	>100 m	Sub-radio Frequency	
3 kHz	10 km	Voice	
30 Hz	1000 km	Extremely Low Frequency	
0 Hz	-	Static	

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## Attachment 8.4

### Wavelength to Frequency Relationship

Frequency			Wavelength	
1 Hz				
10				
1 Hz			3105 miles	3000 km
10 Hz			18,628 miles	30,000 km
60Hz		Powerline	3105 miles	3000 km
1000 Hz	1 kHz		1863 miles	300 km
10 kHz			186 miles	30 km
100 kHz			9836 miles	3000 meters
100 kHz	1MHz	AM radio	984 ft	300 meters
10 MHz			98.4 ft	30 meters
27 MHz		Many RF heat Sealers	36.4 ft	11
30 MHz			32.8Ft	10
100 MHz		FM radio	Ft9.8	3
300 MHz			3.28	1
1000 MHz	1 GHz		11.8 inches	30 cm
2.45 GHz		Microwave ovens	4.8	1.2
10 GHz		Satellite data links	1.18	3
400 GHz		Visible light, red	0.03 mil	(0.75 um; 7500 Angstrom)
750 THz		Visible light, purple		
3,000,000 THz		x-Ray		
50,000,000 THz		Gamma Rays		